mile tha .appear to be caused by closing of expansion joints in old concrete. Center joint cracked but crack is tightly closed. Transverse cracks appear to have been sealed last year. No ravelling or distortion of surface. No signs of failure other than bumps over joints.

May 23, 1945: *Crack interval on west mile of eastbound lane is now 44 feet. Some cracks have resealed themselves over a portion of the width. Cracks have not been poured during last year. A few are beginning to ravel. It does not appear that any maintenance has been performed on the surface during the past year. No new blow-ups observed. Holes dug at edge indicate thickness at edge to be slightly less than two inches. Bituminous concrete not stuck to concrete at crack—nor at edge where there is no crack. Longitudinal cracking in middle of outside lane, showing up in east mile.*

June 27, 1946: *Crack interval on west mile of eastbound lanes 41 feet. Now six bumps in west mile of eastbound lane due either to blow-ups or expansion joints. Center lane appears much drier than outside lanes, probably because of less traffic on inside lane. Longitudinal cracks eight or ten inches from edge beginning to appear due to bituminous resurfacing overhanging edge of concrete. Cracks have not been sealed but a small amount of patching of ravelled cracks has been done.*

EFFECT OF EXPERIMENTAL SUBGRADE TREATMENTS ON PAVEMENT FAULTING AND PUMPING

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SYNOPSIS

This report of a study of the effect of various subgrade treatments on the performance of a heavily traveled, concrete pavement constructed on plastic, silty-clay soils was conducted as a co-operative investigation by the State Highway Commission of Indiana and the Joint Highway Research Project of Purdue University.

One of the many problems in the design of concrete pavements is the selection of the proper base or subgrade to aid the pavement in withstanding the volume and weight of modern traffic. With this in mind, the State Highway Commission of Indiana, during the construction of U.S. Highway No. 30 in 1937, installed seven test sections with differently treated subgrades. Many structural failures have developed on this highway. A study of these failures offers a means of evaluating the effects of the various subgrade treatments on the pavement performance by comparison with the untreated portions. Aerial strip maps were used as one means of evaluating pavement performance.

The performance data indicate that six of the subgrade treatments improved the concrete pavement performance. Granular base courses contributed the most, the result of their use being a pavement of nearly as good a riding quality today as at the time of construction nine years ago. The mixing of bituminous materials with the fine-grained subgrade soil improved the pavement performance but not as effectively as did the granular base courses. No significant difference was readily apparent in the pavement performance on the bituminous treated sections, although all three treatments improved the performance in comparison with untreated sections.

With the increase in volume and weight of highway traffic during the past few years, many States have encountered serious problems in connection with structural failures on high-type pavements. The extrusion of fine-grained subgrade materials from beneath concrete pavements by pumping action is a major cause of a large portion of the failures. It is agreed that pumping occurs only when a combination of the following factors are present: a fine-grained subgrade soil, wet subgrade conditions, and heavy traffic loads. Possibly greater refinement in pavement design would tend to reduce the difficulty with wet subgrades, and more rigid enforcement of the maximum truck weight laws would reduce the heavy loads. Likewise, construction of base courses or subgrade treatments for heavily traveled roads on fine-grained soils appears to be a logical correction.

In 1937, the State Highway Commission of Indiana, during the construction of the dual pavement U.S. Highway No. 30, installed seven test sections with differently treated subgrades in the eastbound lanes. On this portion of U.S. Highway No. 30 are present the elements necessary for failures of the pavement due to pumping action; namely, heavy traffic, fine-grained subgrade soils, and wet subgrade conditions. In 1940 pumping action (Fig. 1), which has resulted in a large number of structural failures in the concrete pavement, began.

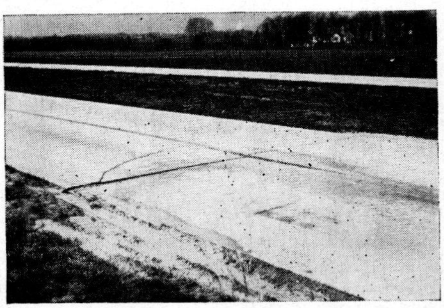

Figure 1. Pavement Pumping, U.S. Highway No. 30. Note mud stains and cracks.

Since construction, differences between the performances of the experimental sections and the untreated portion have become more and more noticeable. In the summer of 1946 the authors made a detailed survey of the road in order to evaluate the effects of these treatments. Faulting at joints was selected as the criterion on which the evaluation would be based. Many factors contributing to this faulting were considered, the most important of which are subgrade soils, traffic, types of load transfer devices used, and profile (cut, fill, gradient). The survey included the test sections, the opposite untreated lane, and adjoining untreated portions of both lanes so that the test sections might be compared to untreated sections subjected to the same influences.

After the field survey had been made and this report nearly completed, an aerial strip map of U.S. Highway No. 30 was secured. The information shown on this map was of such a valuable nature that portions of it have been reproduced and inserted with explanatory paragraphs throughout the text of this report.

PREVIOUS INVESTIGATIONS

The earliest evidence of probable failure and the ultimate cause of many failures in concrete pavements is pavement pumping. Pumping of concrete pavements is described by Woods and Shelburne (*1*)[1] as follows: "Pumping of rigid pavements at joints, cracks and along the edge consists of the deflection of the slab under moving wheel loads which results in the ejection of water carrying particles in suspension. As the action progresses, cavities develop in those areas immediately under the pumping slabs, thereby diminishing or removing the subgrade support."

The conditions necessary for pumping to develop as described by Whitton (*2*) are heavy axle loads, joints or cracks in the pavement, unsuitable subgrade soils and "free" water under the slab. Under such conditions pumping will progress until excessive failures in the pavement slabs occur and portions have to be removed and replaced.

Pumping of concrete pavements had not been considered a serious problem until about 1940. One of the first references to pumping was by Forrer (*3*) in 1939. After 1940, accelerated by war-time traffic, pumping developed rapidly. It was estimated by Woods and Havey (*4*) that by 1944, 5 percent of the concrete pavements in Indiana were pumping. With the growing seriousness of the problem many investigations and studies were carried on concerning the cause of pumping and effective methods of correcting it. The Highway Research Board organized a project committee to study the problem of pumping. To date two reports have been issued by this committee (*2*, *5*). Numerous other papers have also

[1] Italicized numbers in parentheses refer to the list of references at the end of the paper.

been written on the subject (*6, 7, 8, 9, 10, 11, 12, 13, 14*).

From these papers it can be seen that a fair measure of effectiveness in correcting pumping can be achieved by mudjacking various materials and mixtures (asphalt, soil, cement) under the pavement. Recent work has been performed by Green (*15*) in developing a jacking device to lift pavements to proper elevations before hot bituminous materials or cement slurrys are pumped under them. Tiling has also been investigated as a means of reducing pumping (*16*).

Granular base courses have been used successfully as a means of preventing pumping. Allen and Marshall (*17*) report that predominantly granular sub-base courses used in Ohio have been effective in preventing pumping. However, some pumping did develop in base courses of low permeability. Studies in Tennessee (*18*) were made by mixing sand and gravel with the existing clay soils to prevent pumping.

SIGNIFICANT FEATURES OF U. S. HIGHWAY NO. 30

Design

For the evaluation of the seven differently treated test sections on U.S. Route No. 30, a detailed study was made of approximately nine miles of the highway in Lake County, Indiana, which is the most northwesterly county of the State. The section lies between the intersection of U.S. Route No. 30 with U.S. Route No. 41 and the C and O Railroad.

U.S. Route No. 30 is a roadway of modern design. In cross-section the 200-ft right-of-way contains two 22-ft slabs, separated by a 44-ft dividing strip containing a center ditch, and a 56-ft strip on either side of the pavement. The pavement slabs are of 9–7–9-in. in section. The slabs are reinforced with steel mesh and have expansion joints normally spaced at 40-ft intervals. No contraction joints were used. A typical cross-section of the slab is shown in Figure 2.

Figure 8 is a portion of an aerial strip map of U.S. Highway No. 30 from which a plan view of the road as constructed may be seen. It should be noted that this view of the highway, as well as all other strip map views included in this report, is only one-half of an entire strip map. The other half consists of a similar view of the highway. When the two views are observed together stereoptically, relief may be seen.

The grading of the highway was completed in 1936. In 1937, contracts were let for paving. One of these contracts included the seven subgrade treatments to be constructed in the eastbound lane of the dual lane pavement. These experimental sections included base courses constructed with granular materials (sand, stabilized material), subgrade treated with limestone dust, subgrade treated with bituminous materials (tar, emulsified asphalt, liquid asphalt), and subgrade saturated with water.

Two major types of expansion joints were installed, namely, A-2 and G joints. Figure 2 shows cross-sections of both types. The type G joint is no longer used by the State Highway Commission of Indiana. Type G joints were used between Station 15+00 to 125+00, and Type A-2 joints in the remaining portion of the area surveyed. At intersections a few type D-1 and 1-in. cork joints were used.

In 1944, 6-in. longitudinal drains were constructed at an approximate depth of 3 ft along the outer edges of both lanes throughout the majority of the portion of the highway covered in this report and backfilled with porous granular materials. Exceptions to these installations were made through the small area of sandy subsoil and the test sections having 6-inch sand and 3-inch stone stabilization base courses.

Construction of the Test Sections

The test sections were all constructed in the eastbound lanes. They are not all continuous, being separated by intersections with railroads and major highways.

The station numbers of the test sections and other significant features are given in Table No. 1. All railroad and major highway intersections were omitted from this survey as they were not considered representative.

The treatments applied to the seven test sections varied greatly in type and method of construction. As the work was experimental, several changes from the specifications were made during construction. Typical cross-sections of the finished experimental sections are shown in Figure 3. The following summaries are only brief descriptions of the na-

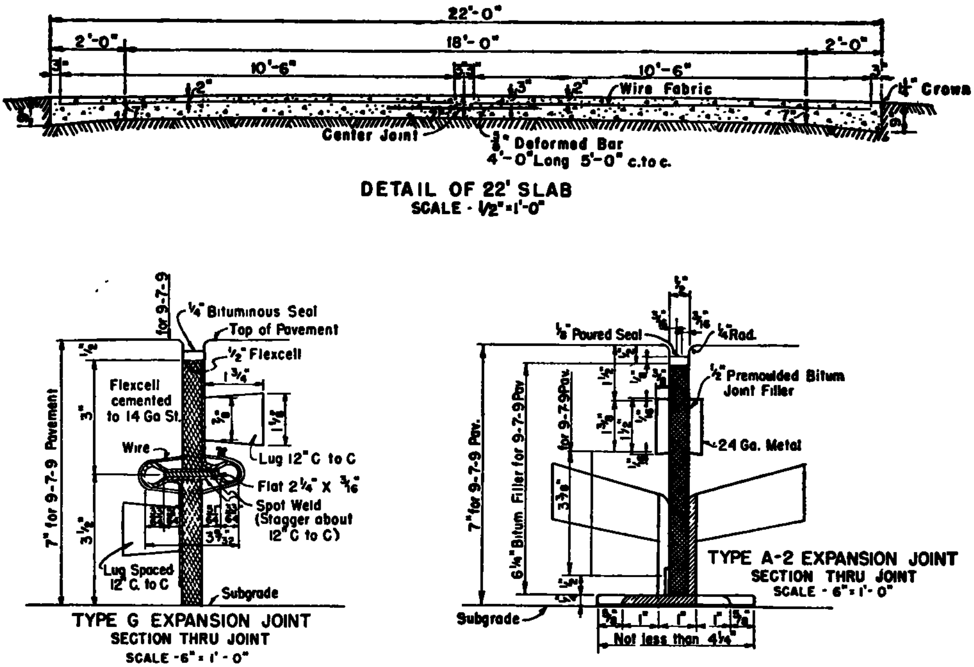

Figure 2. Slab and Expansion Joint Details

TABLE 1

U.S. ROUTE NO 30. LOCATION OF TEST SECTIONS AND OTHER SIGNIFICANT FEATURES

Station	Length	Installation	Remarks
15+00			Start of Survey—Intersection with U S 41
21+55 to 23+75		Under pass—N Y C R R	Omitted from Survey
101+50 to 118+50		Over pass—Pa. R R.	" " "
145+00 to 170+00	2,500	Sand Base Course	
170+00 to 195+00	2,500	Limestone Dust Treatment[a]	
195+00 to 221+00	2,600	Water Saturation "	
226+00 to 245+50		Over pass -C &E R R.	Omitted from Survey
250+00 to 275+00	2,500	Tar (TC) Treatment	
275+00 to 300+00	2,500	Emulsified Asphalt (AES-1) Treatment	
300+00 to 311+75 & 313+50 to 326+25	2,500	Liquid Asphalt (MC-1) Treatment	
311+75 to 313+50		Intersection of SR 55	Omitted from Survey
325+75 to 360+00	3,325	Stabilized Material Base Course	
388+75 to 395+75		Intersection SR 53	Omitted from Survey
475+00			End of Survey-Intersection with C.&O. Railroad.

[a] Subgrade treatments are in Eastbound lane only.

ture and method of construction of the experimental sections.

Sand Base Course

This treatment consisted of a 6-in. layer of dune sand placed on the natural subgrade. The subgrade was excavated to grade by a scraper and sand spread to a loose depth of 7 in. and thoroughly wet before paving. Figure 4 shows a view of the sand subgrade being prepared for paving. This section handled easily during construction and held the paving forms to correct grade and alignment.

The dune sand used was material that was available locally and had the following gradation:

Screen Size	*Percentage Retained*
No. 40	0.0
No. 270	95.6

The results of tests on the natural subgrade soils of this test section are summarized in Table 2.

Six-inch subsurface lateral drains (Fig. 4) were installed approximately every 300 ft beginning at Station 145+00 to insure drainage of this course.

Limestone Dust Treatment

This subgrade treatment consisted of a 3-in. layer of compacted earth mixed with standard commercial agricultural limestone dust. The subgrade was excavated $\frac{3}{4}$ in. below the normal subgrade elevation and scarified and disced

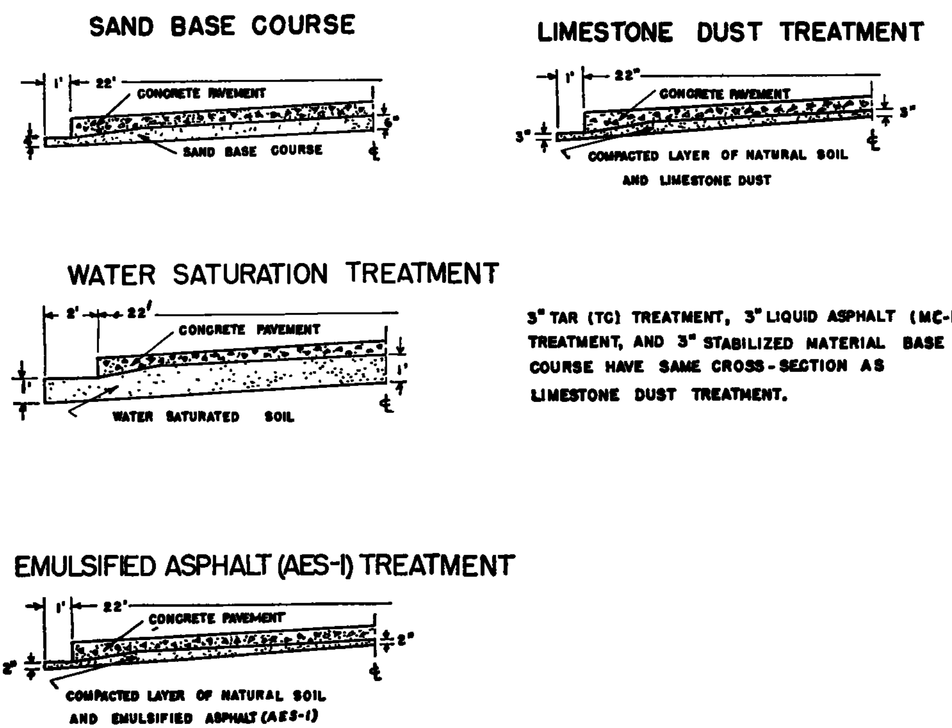

Figure 3. Typical Cross-sections of Experimental Subgrades

TABLE 2
SUBGRADE SOIL TESTS, SAND BASE

Station	Mechanical Analysis			Physical Characteristics			
	Sand	Silt	Clay	Liquid Limit	P.I.	Shrinkage Limit	U.S.B.P.R. Classification
	%	%	%				
145+00	9	44	47	47	23	17	A-7
150+00	14	37	49	31	16	20	A-4 Pl.
155+00	12	40	48	39	19	17	A-7
160+00	15	38	47	34	16	17	A-7
165+00	45	21	34	37	19	13	A-7

to a depth of 3 in. The limestone dust was added uniformly over the surface in an amount of about 125 lb per sq yd. The mixture of limestone dust and soil was then thoroughly disced, bladed and rolled with a 10-ton roller.

The results of tests on the natural subgrade soils of this test section are summarized in Table 4:

Water Saturation Treatment

This treatment consisted in thoroughly wetting the subgrade to a depth of 12 in. The subgrade was scarified to a depth of 12 in. and ponded with water for three or four days.

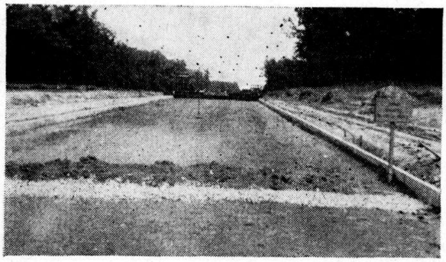

Figure 4. Sand Subgrade Ready for Paving. Lateral Drain in Foreground

TABLE 3
SCREEN ANALYSIS OF LIMESTONE DUST

Screen Size	Percentage Retained	
	Test 1	Test 2
No. 4	11.3	11.1
No. 10	46.3	32.2
No. 40	75.0	70.0
No. 270	93.8	96.0

TABLE 4
SUBGRADE SOIL TESTS, LIMESTONE TREATMENT

Station	Mechanical Analysis			Physical Characteristics			
	Sand	Silt	Clay	Liquid limit	P.I.	Shrinkage Limit	U.S.B.P.R. Classification
	%	%	%				
170+00	15	41	44	36	19	15	A-6
175+00	21	22	47	38	20	16	A-7
180+00	14	32	54	33	16	15	A-7
185+00	17	41	42	37	18	15	A-7
190+00	5	53	42	36	16	17	A-7
195+00	12	39	49	46	24	16	A-7

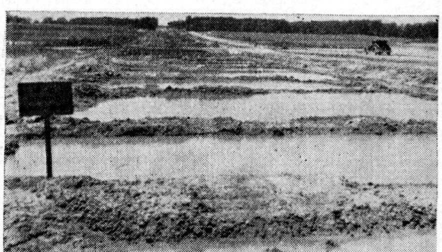

Figure 5. Ponded Subgrade—Water Saturation Treatment

Figure 5 shows a view of the ponded subgrade. After ponding, 3 in. of dry dirt were added to permit equipment to shape the subgrade. During shaping operations, the subgrade was sprinkled from time to time to insure thorough saturation of the top 3 in. Difficulty was encountered in rolling and in setting and keeping forms to correct line and grade.

The results of tests on the natural subgrade soils of this test section are summarized in Table 5.

TABLE 5
SUBGRADE SOIL TESTS, WATER TREATMENT

Station	Mechanical Analysis			Physical Characteristics			
	Sand	Silt	Clay	Liquid Limit	P.I.	Shrinkage Limit	U.S.B.P.R. Classification
	%	%	%				
200+00	12	47	41	39	20	18	A-7
205+00	18	50	32	41	17	21	A-7
210+00	16	39	45	36	17	15	A-7
215+00	12	38	50	33	15	15	A-7
220+00	13	40	46	31	12	17	A-4

Tar (TC) Treatment

This subgrade treatment consisted of a 3-in. compacted layer of bituminous treated subgrade soil. The subgrade was brought to shape 3 in. below normal subgrade elevation, and the excavated material placed in windrows on either shoulder. A prime coat of 0.25 gal per sq yd of tar (TC) was applied. After 24 hours, 3 in. of loose dirt was bladed uniformly over the surface and tar (TC) applied at the rate of 0.95 gal per sq yd. After discing this material, another inch of loose dirt was spread over the surface and disced in. During discing, and before the bituminous material was applied, water was added to facilitate the mixing operation. It was necessary to add a considerable amount of water to raise the moisture content to a point where the tar would mix with the soil. After final discing the material was compacted with a 10-ton roller.

The results of tests on the natural subgrade soils of this test section are summarized in Table 6.

Emulsified Asphalt (AES-1) Treatment

This subgrade treatment consisted of 2-in. compacted layer of bituminous treated subgrade soil. The subgrade was brought to shape by a subgrader which placed the excavated material in windrows on either shoulder. A prime coat of 0.25 gal per sq yd of emulsified asphalt (AES-1) was applied. After priming, about 2 in. of loose dirt was bladed uniformly over the surface and 0.45 gal per sq yd of AES-1 applied. After this application another inch of loose dirt was spread over the surface, and a second application of AES-1 in the amount of 0.65 gal per sq yd applied. The material was then mixed by

TABLE 6

SUBGRADE SOIL TESTS, TAR TREATMENT

Station	Mechanical Analysis			Physical Characteristics			
	Sand	Silt	Clay	Liquid Limit	P.I.	Shrinkage Limit	U.S.B.P.R. Classification
	%	%	%				
250+00	37	36	27	34	16	13	A-7
255+00	22	38	40	31	16	13	A-6
260+00	23	43	34	28	13	12	A-4 Pl.
265+00	17	44	39	36	17	15	A-7
270+00	27	48	25	33	13	14	A-4
275+00	15	65	20	39	20	14	A-7

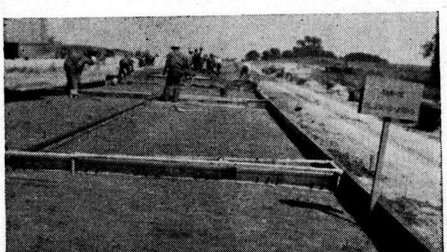

Figure 6. Tar Treated Road Ready for Paving. Type A-2 Expansion Joint in Foreground

blading and discing. After a delay in construction, water was added and the material again mixed and rolled with a 10-ton roller.

The results of tests on the natural subgrade soils of this test section are summarized in Table 7.

Liquid Asphalt (MC-1) Treatment

This subgrade treatment consisted of a 3-in. compacted layer of bituminous treated earth. The subgrade was brought to shape 3 in. below normal subgrade elevation. The excavated material was placed in windrows on either shoulder. After this operation a prime coat of 0.30 gal per sq yd of MC-1 was

TABLE 7

SUBGRADE SOIL TESTS, EMULSIFIED ASPHALT TREATMENT

Station	Mechanical Analysis			Physical Characteristics			
	Sand	Silt	Clay	Liquid Limit	P.I.	Shrinkage Limit	U.S.B.P.R. Classification
	%	%	%				
280+00	32	28	40	39	21	13	A-7
285+00	27	34	39	32	15	15	A-7
290+00	29	28	43	42	24	14	A-6
295+00	28	30	42	45	22	20	A-7
300+00	22	61	17	52	19	22	A-7

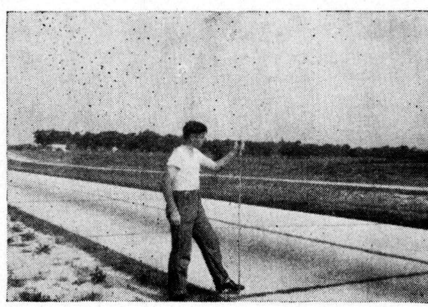

Figure 7. Measurement of Faulting at an Expansion Joint

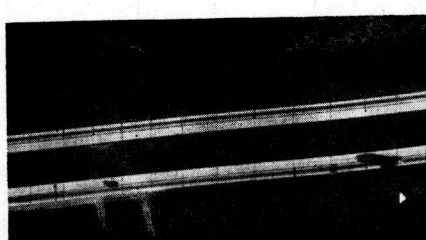

Figure 8. Aerial Strip Map of a Portion of U. S. Highway No. 30 West of the Test Sections. The subgrade soils are silty clay and neither lane has received treatment. The lane at the bottom of the photograph is the eastbound lane.

applied. Loose dirt was bladed in from shoulders and MC-1 applied in three equal applications. The mixture was disced after each application of MC-1 and compacted to a 3-in. layer. Water was added as needed to facilitate mixing and rolling. From Stations 300+00 to 311+75, 1.5 gal per sq yd of MC-1 was used and the material rolled with a 10-ton roller; from Stations 313+50 to 326+75, 2.5 gal per sq yd of MC-1 was used and the material rolled with a 10-ton roller.

The results of tests on the natural subgrade soils of this test section are summarized in Table 8.

TABLE 8
SUBGRADE SOIL TESTS, LIQUID ASPHALT TREATMENT

Station	Mechanical Analysis			Physical Characteristics			
	Sand	Silt	Clay	Liquid Limit	P.I.	Shrinkage Limit	U S.B P.R. Classification
	%	%	%				
305+00	10	44	46	34	16	16	A-7
310+00	30	32	38	45	22	17	A-7
315+00	29	30	41	42	23	17	A-7
320+00	16	45	39	38	20	16	A-7
325+00	27	29	44	45	23	15	A-7

TABLE 9
SUBGRADE SOIL TESTS, STABILIZED BASE

Station	Mechanical Analysis			Physical Characteristics			
	Sand	Silt	Clay	Liquid Limit	P.I.	Shrinkage Limit	U.S.B.P.R. Classification
	%	%	%				
332+00	13	40	47	45	24	15	A-7
337+00	29	39	32	47	26	13	A-7
342+00	27	41	32	47	23	17	A-7
347+00	16	41	43	35	16	14	A-7
352+00	16	54	30	42	22	15	A-7
355+00	38	38	24	25	9	14	A-2
357+00	14	44	42	35	16	15	A-7

Stabilized Material Base Course

This subgrade treatment consisted of a 3-in stabilized base course. The subgrade was excavated to a depth of 3-in below normal subgrade elevation to permit placing of the stabilized material. The material used consisted of a mixture of course limestone and limestone fines which were batched by volumes, mixed in a concrete mixer, and discharged into spreader boxes, which spread it directly on the subgrade. Water was added and the stabilized material rolled with a 10-ton roller.

The results of tests on the natural subgrade soils of this test section are summarized in Table 9.

A sieve analysis of the stabilized material used showed that it fell within the specifications on all sieves. The average analysis of nine tests run on the finished material is given in Table 10.

Figure 9. Aerial strip Map of a Portion of U. S. Highway No. 30 East of the Test Sections. The subgrade soils are silty clay and neither lane has received treatment. The lane at the bottom of the photograph is the eastbound lane.

TABLE 10
SIEVE ANALYSIS, STABILIZING MATERIAL

Sieve Size	Percentage Retained	Specification Limits
1 in.	3.1	0–15
¾ in.	18.7	5–35
½ in.	37.9	20–70
No. 4	63.3	40–75
No. 10	73.2	60–80
No 40	81.0	70–85
No 270	92.5	85–93

Cost of Subgrade Treatments

As these subgrade treatments were of an experimental nature, their cost was necessarily higher than ordinary construction. No estimates of the cost of a large scale subgrade treatment program could be based upon them. The costs of each treatment in ascending order are in Table 12.

The greater cost of the liquid asphalt (MC-1) treatment in comparison to the two other bituminous treatments is due to the larger quantity used.

SUBGRADE SOILS

Although some dune sands were encountered at the beginning of the survey, the subgrade soils at the site consist predominately of plastic silty clays of the Wisconsin drift. In determining the soil profile three methods of approach were used. The first was to prepare a soil profile from existing agricultural maps and descriptions. For this purpose reference was made to the U. S. Department of Agriculture publication, "Soil Survey of Lake County, Indiana," Bushnell and Barrett, 1921.

This publication gave in detail the outlines of the different soil areas at the site and descriptions of the natures of the soils. Although this material is presented from a viewpoint of pedology, it can be readily translated to an engineering viewpoint. This task has been accomplished for Indiana by Belcher, Gregg, and Woods (*20*).

Figure 10. Aerial Strip Map of a Portion of the Test Section with a 6-in. Sand Base Course. The eastbound lane, which contains the base course, is at the bottom of the photograph. The westbound lane is untreated.

TABLE 11

SUMMARY OF TREATMENTS

Treatment		Material Used	
Thickness	Type	Type	Amount Used per sq. yd.
in.			
6	Sand	Uniform Dune Sand	
3	Limestone Dust	Limestone Dust	125 lb
12	Water Saturation	Water	
3	Tar	TC	1.2 gallons
2	Emulsified Asphalt	AES-1	1.35 gallons
3	Liquid Asphalt	MC-1	1 5 & 2.5 gal.
3	Stabilized Mat'l.	Mixture of graded Limestone and Limestone Dust.	

TABLE 12

Treatment	Cost per sq. yd.
12-in. Water Saturation Treatment	$0.10
3-in. Limestone Dust	$0.18
3-in. Stabilized Material	$0 25
3-in. Tar	$0.27
2-in. Emulsified Asphalt	$0 29
6-in. Sand	$0.32
3-in. Liquid Asphalt (MC-1)	$0.44

The second approach for determining the nature of the subgrade soils was to prepare an engineering soils map of the area from aerial photographs. In addition to furnishing information as to soils types at the site, this method gives the surface drainage pattern of the land along the highway.

To check the accuracy of the two methods and to determine materials used in fill sections, a limited soil survey, consisting of auger borings was made. The original soil survey on which these treatments were based was also used in determining the soil types. Good agreement was found between data gathered in the field and that obtained from agricultural maps and aerial photographs.

In the area of this survey, the subgrade soils can be divided into two types, a plastic silty clay and a cohesionless dune sand. The sandy-soil area is found on the west end of the highway from the start of the survey to Station 51+00. For a part of this distance the road is constructed on the dividing line between sand and silty-clay soils, and although the subgrade is predominately sandy a few small stretches are of silty clay. All fills in this area were made of sand.

In the silty-clay area, on which all of the test sections are constructed, weathering and erosion have caused a marked contrast between depressed and elevated areas. In all elevated areas, through which cuts were made, the subgrade generally consisted of the parent soil of the area, which is a silty clay with a trace of fine sand. The depressions were found to have a soil profile consisting of black organic silt over a gray silty clay on top of the parent soil. The black organic silt was not entirely removed from the fill sections. Generally only that portion containing fibrous material was removed. No special borrow material was used, therefore the same brown silty clay as found in cuts is the predominate soil directly beneath the pavement in the fill sections. A negligible amount of black organic silt and gray silty clay, evidently resulting from cutting the flat slopes of the transition area between depressions and elevations, was found as fill material. Considering only pavement failures due to pumping, which is dependent on the soil directly under the pavement, this area could be considered to have a uniform subgrade soil of brown silty clay with a trace of fine sand. However, some failures may be attributed to settlement and movement of fills over depressions where a considerable quantity of the black organic silt exists. For this reason, a division of the highway into cut and fill sections for purposes of analysis of the pavement performance was considered advisable. The fills vary in thickness up to 10 ft with the average being about 4 ft.

TABLE 13
SILTY CLAY SUBGRADE

	Average	Range
Sand	20%	5%-45%
Silt	41%	21%-65%
Clay	39%	17%-54%
Liquid Limit	38	25 -52
Plasticity Index	18	9 -26

During construction of the test sections numerous classification tests were run on the test section subgrade soils. Forty-one tests give the gradations and physical characteristics of the silty clay subgrade in Table 13.

The average maximum density of the silty clay soil from four Proctor Tests is 110.0 lb per cu ft at 18 percent moisture. For lack of sufficient data no evaluation of the effect of subgrade compaction on the pavement performance could be made.

CLIMATE

A factor that greatly influences the performance of a concrete pavement is climate. As the climatic condition does not vary over the small area being considered, its effect on the pavement performance cannot be used as a variable in comparing one section of pavement with another. However, since the condition of the subgrade can be greatly influenced by the weather conditions at time of grading operation, it is interesting to note moisture conditions that occurred both during and after construction.

Data obtained on rainfall at Valparaiso, Indiana, which is about 20 miles east of the test sections, show that during grading operations in 1936 a very dry season existed. The autumn months following completion of the grading operations were months of excessive rainfall. The months of 1937 preceding laying the paving in August were also months of above normal rainfall. These conditions, namely, performing grading operations during dry weather and then leaving the subgrade exposed to above normal rainfall for nearly a year before paving, would tend to result in a wet subgrade of low density. The ultimate result of construction under these conditions might well be poorer pavement performance than would be obtained if more normal moisture conditions existed during construction.

The normal rainfall of this area is sufficient to allow pumping action to develop as the 35 year mean is 34.3 in. per year. From the construction until 1944, at which time the longitudinal drains were installed due to the seriousness of the pumping, the rainfall each year was above the 35 year mean. The highest rainfall was in 1941 when it was 11.77 in. above normal. The wet subgrade resulting from this rainfall, combined with the fine-grained subgrade soils and heavy war-time traffic, during this period furnished ideal conditions for the pavement pumping.

TRAFFIC

U.S. Highway No. 30, is an arterial highway carrying traffic between Chicago and the East. Data from the 1943 surveys of the Indiana Highway Planning Survey shows that for the portion of the highway covered in this report, the estimated daily traffic for that year was 3000 vehicles, 1100 of which were commercial vehicles. A traffic count on August 20, 1946 showed that it carried 2620 vehicles, 599 of which were commercial, between 6 A.M. and

2 P.M. These data, although meager, indicates that U.S. Highway No. 30 is heavily traveled.

DATA AND DISCUSSION

Pumping

Although this paper is concerned with pumping and faulting of pavements, no data were gathered during this survey of the number of pumping joints. Many joints had stopped pumping, either as a result of the installation of longitudinal drains in 1944, or because the pavement failures had progressed to such a degree that pumping action no longer existed. As all of the joints that had been subjected to pumping action at one time or another could not be determined, and as the survey was made at a time of year when pumping was not prevalent, comparisons of pavement performance could not be based on the number of joints that were actively pumping at the time of the survey.

A survey by Shelburne (*19*) in April, 1942, of 24 miles of U.S. Highway No. 30, between U.S. Highway 41 and Valparaiso, showed severe pumping at that time. Of the 6600 joints inspected by Shelburne 33 percent showed evidence of pumping. In the eastbound lane, only 2.8 percent of the joints on sandy subgrade were pumping as compared to 42.2 percent on silty clay subgrade. No pumping was found in the test sections with sand and stabilized material base courses.

Since it was not possible to determine the actual pumping at the time of the survey and since faulting does eventually occur at all pumping joints, it is reasonable to assume that a major portion of the present faulting is a direct result of pumping. On this basis the words "faulting" and "pumping" can be used almost interchangeably. This should be borne in mind as the data are concerned mainly with faulting.

Method of Securing and Tabulating Field Data

For the purpose of measuring faulting, a device was constructed consisting of a hollow tube attached to two legs. A scale was attached at eye level on the top of the tube. A rod run through the tube was adjusted so that the top of the rod was level with the zero reading on the scale when the device was set on a flat surface. To measure the faulting at a joint the legs of the device are placed on the rear slab so that the hollow tube extends out over the faulted slab. The rod is lowered through the hollow tube so that it touches the faulted slab. The amount of faulting is then read directly from the scale. Figure 7 shows faulting at a joint being measured by this method. By this method readings accurate to about a sixteenth of an inch can be taken very quickly.

Readings at an expansion joint were taken at four locations, namely, at both edges of the inner and outer slabs. Considerable variation was found in the amount of faulting at the edges of any one slab. The maximum value was not always at the outside edge as might be expected. Therefore it was decided for the purpose of this report to define the faulting of a slab as the average of the two readings.

At patched joints, the patching material was removed before the faulting was measured. When failures were encountered on each side of a joint in the outer slabs, the amount of faulting was measured from the adjacent inner slabs.

The amount of faulting at all joints was measured and the number of cracks in the concrete pavement was counted between Stations 15+00 and 475+00 except at sections as noted in Table No. 1. This strip included the seven test sections in the eastbound lane, the opposite untreated westbound lane and adjoining portions in both lanes.

Due to the different lengths of various sections, the amount of faulting was computed as the number of inches per 1000 ft for comparison purposes and is tabulated as such. This faulting is the summation of all faulting that could be measured by the method previously described. The number of cracks counted is the number of easily visible transverse, longitudinal, and corner cracks. Very few fine hairline cracks were noted and they were not considered. If an aerial strip map of the highway had been available at the time of the survey, it would not have been necessary to count in the field the number of cracks as all the major cracks are easily visible on the maps. It is significant to note that in the area surveyed, pumping and faulting were not found at cracks, but were confined to expansion joints and along the edge adjacent to joints.

The faulting at joints and the number of cracks for the entire section surveyed are shown in Tables 14, 15. Table 14 shows these data for the seven test sections and opposite untreated lane, while Table 15 shows the corresponding data for the adjoining portions of both lanes.

caused every crack is impossible. However, for comparative purposes a rough assumption may be made, namely, that the cracks in the inner lanes are caused by temperature, an equal number in the outer lanes are caused by temperature and the remainder in the outer lanes are caused by traffic. Working on this

TABLE 14

JOINT FAULTING AND CRACK COUNT, U.S. HIGHWAY NO. 30

Subgrade Treatment (Eastbound Lane only)	Length	East Bound Lanes				West Bound Lanes			
		Faulting (in per 1000 ft.)		No. of Cracks per 1000 ft.		Faulting (in. per 1000 ft.)		No. of Cracks per 1000 ft.	
		Inner Slab	Outer Slab	Inner Slab	Outer Slab	Inner Slab	Outer Slab	Inner Slab	Outer Slab
	ft.								
6-in. Sand Base Course	2,500	0.9	2.4	8.4	14.8	1.1	5.9	7.6	18.4
3-in. compacted layer of soil mixed with limestone dust	2,500	1.2	4.6	10.4	29.2	0.7	4.3	1.6	5.6
12-in. Water Saturated Soil	2,600	2.9	15.7	21.0	51.0	0.6	2.4	1.2	2.7
3-in. compacted layer of soil treated with Tar (T C)	2,500	1.5	5.7	12.4	24.0	1.5	7.6	13.2	29.6
3-in. compacted layer of soil treated with emulsified Asphalt (AES-1)	2,500	1.4	6.9	10.4	26.0	1.4	7.9	18.4	38.8
3-in. compacted layer of soil treated with a cut-back Asphalt (M C-1)	2,500	1.2	4.7	6.4	16.0	1.5	4.4	16.0	22.8
3-in. stabilized material Base Course	3,325	1.3	2.1	18.0	22.6	1.4	4.6	9.6	23.4

TABLE 15

JOINT FAULTING AND CRACK COUNT, U.S. HIGHWAY NO. 30

Location	Length	Subgrade Soil	Eastbound Lanes				Westbound Lanes			
			Faulting(in. per 1000 ft.)		No. of Cracks per 1000 ft.		Faulting(in. per 1000 ft)		No. of Cracks per 1000 ft.	
			Inner Slab	Outer Slab	Inner Slab	Outer Slab	Inner Slab	Outer Slab	Inner Slab	Outer Slab
	ft.									
West of Test Sections	3,380	Sand					1.6	3.4	4.5	11.5
	2,830	Sand	1.6	3.0	10.6	24.4				
West of Test Sections	7,700	Silt & Clay					1.3	7.6	8.8	24.6
	8,250	Silt & Clay	1.7	7.8	17.0	33.9				
Between Test Sections	950	Silt & Clay	1.8	6.1	14.7	22.1	0.8	2.9	5.3	7.4
East of Test Sections	10,800	Silt & Clay	1.8	11.7	27.6	48.0	0.8	2.4	26.3	36.0

Pavement Cracking

To evaluate the effect of the subgrade treatment on the performance of the concrete pavement by the number of cracks, it is first necessary to determine which cracks are caused by the action of traffic and which by changes of temperature. To determine what

assumption, an approximate evaluation of the effect of the subgrade treatment may be made. Table 16 gives the difference between the number of cracks in outer and inner lanes for the various sections considered. For 37,875 ft of untreated westbound lane on silty clay subgrade, the average difference in the number of cracks between inner and outer slabs is 11.3 per 1000 ft. The range of differences in the number of cracks between inner and outer slabs is from 1.5 cracks per 1000 ft opposite the test section with the water saturated subgrade to 20.4 cracks per 1000 ft opposite the test section with the emulsified asphalt treated subgrade section. This indicates a large variation in the number of cracks within a lane. For 19,950 ft of untreated eastbound lane on silty clay subgrade, the average difference in the number of cracks between inner and outer slabs is 19.0 per 1000 ft. The range of differences is from 7.4 cracks per 1000 ft for the short 950 ft strip between the test sections to 20.4 cracks per 1000 ft for the strip east of the test sections. This shows that the difference in the number of cracks between inner and outer slabs, as well as the total number, is considerably more in the untreated portion of the eastbound lane than in the untreated westbound lane. For this reason, a comparison of the test sections to untreated portions of the same lane appears the most logical.

TABLE 16

PAVEMENT CRACKING, U. S. HIGHWAY NO. 30

Location	Subgrade Treatment[a]	Cracks in Outer Slab Minus Cracks in Inner Slab (no. per 1000 ft)	
		East-bound Lane	West-bound Lane
Sandy Area west of test sections	None	13.8	7.0
Silty Clay Area west of test sections	None	16.9	15.8
	6-in. Sand	6.4	10.8
	3-in. Limestone Dust	18.8	4.0
	12-in. Water Saturation	30.0	1.5
Silty Clay Area Between Test Sections	None	7.4	2.1
	3-in. Tar	11.6	16.4
	2-in. Emulsified Asphalt	15.6	20 4
	3-in. Liquid Asphalt	9.6	6.8
	3-in. Stabilized Material	4.6	13.8
Silty Clay Area East of Test Sections	None	20.4	9.9

[a] Subgrade Treatment in Eastbound lane only.

Figures 8 and 9 are representative views of U. S. 30 in silty clay soil areas where neither lane has received subgrade treatment. They show that there is more cracking in the eastbound than in the westbound lane especially in the area east of the test sections.

Considering only the eastbound lane, the treatments compare on the basis of the difference in the number of cracks between inner and outer slabs as in Table 17.

TABLE 17

Treatment	Cracks in Outer Slab Minus Cracks in Inner Slab (Number per 1000 ft.)
None (19,950 ft of silty clay subgrade)	19 0
12-in Water Saturation. ...	30 0
3-in Limestone Dust .	18.8
2-in Emulsified Asphalt	15.6
None (2830 ft of sandy subgrade)	13 8
3-in Tar	11.6
3-in Liquid Asphalt (MC-1)	9.6
6-in Sand Base Course	6.4
3-in Stabilized Material Base Course	4.6

From Table 17 it can be seen that the test sections with the sand and stabilized material base courses contain by far the least difference in the number of cracks. With the exception of the water saturated, all treated sections show less cracking than the untreated silty subsoil areas. No further conclusions as to the effect of the subgrade treatments on pavement performance are believed warranted due to the difficulty in analyzing the cause of the cracks.

Faulting at Different Type Expansion Joints

Two types of expansion joints, A-2 and G, were used on the portion of U.S. Highway No. 30 considered in this survey. Figure 2 shows cross-section views of these joint types including the design of the load transfer devices. Type G joints were used in both lanes from Station 15+00 to Station 125+00. Type A-2 joints were used in both lanes for the remainder of the section surveyed. To compare the effect of the two different load transfer devices in these expansion joints it is necessary to consider areas where similar subgrade and traffic conditions exist. Since the natural sandy soil area contains only one type of joint, it must be omitted from the comparison. Likewise, the test sections must be omitted since they have different subgrades. Table 18 shows the amount of faulting in the outer slabs for the silty clay subgrade soils where no subgrade treatment was used. In considering only silty clay subgrade, there are 32,825 ft of westbound lane with A-2 joints and 5050 ft with G joints. In the westbound lane, the average faulting for G joints is 6.9 in. per 1000 ft; for A-2 joints 4.5 in. per 1000 ft. This indicates the A-2 joint to be superior in this lane. However, the range for A-2 joints at various sections is from 2.4 to 8.3 in. per 1000 ft. This shows that the type G joint may have greater or lesser faulting than A-2 joints when comparisons over equal lengths of highway in this lane are made. In the eastbound lane, the average faulting for G joints is 5.0 in. per 1000 ft; for A-2 joints 11.5 in. per 1000 ft; which indicates the G joint to be superior in this lane. It is believed, from the inconsistency of the results obtained from these data, that no definite conclusion can be reached as to the superiority of either type. Therefore, for the purpose of this report the two joint types will be assumed to exert equal influences on the amount of faulting occurring at them.

TABLE 18

FAULTING AT TYPES G AND A-2 EXPANSION JOINTS, U.S. HIGHWAY NO. 30

Silty Clay Subgrade Soils, No Subgrade Treatment

Stations	Distance	Faulting in Outer Slabs in. per 1000 ft.	
		East-bound Lane	West-bound Lane
G Joints			
	ft		
51+00 to 101+50	5,050	5.0	6.9
A-2 Joints			
118+50 to 145+00	2,650	12.6	8.3
145+00 to 170+00	2,500		5.9
170+00 to 195+00	2,500		4 3
195+00 to 221+00	2,600		2.4
221+00 to 226+00 and 245+50 to 250+00	950	6.1	2.9
250+00 to 275+00	2,500		7.6
275+00 to 300+00	2,500		7 5
300+00 to 311+75 and 313+50 to 326+75	2,500		4.4
326+75 to 360+00	3,325		4 6
360+00 to 388+75 and 395+75 to 475+00	10,800	11.7	2.5
Average		11.5	4.5

Faulting of Inner Slabs

Faulting of the inner slabs is considered to be caused primarily by passing traffic and traffic crossing to the inner slab around curves. However, up to the present time this traffic is almost negligible in comparison to the traffic carried by the outer slabs. This faulting is tabulated in Tables 14 and 15. The maximum faulting noted on the inner slabs was at the test section with the water saturated subgrade. Here the faulting amounted to 2.9 in. per 1000 ft or an average of 0.11 in. per joint. The minimum faulting noted was on the inner slabs of test section with the 6-in. sand subgrade. This faulting amounted to 0.9 in. per 1000 ft or an average of 0.036 in. per joint. At a number of joints, it was found that the rear slab was lower than the forward slab. This could not be caused by traffic but may be attributed to uneven finishing of the joint during construction. Due to the difficulty in determining whether or not these small readings are a measure of faulting and the difficulty in comparing the traffic use of the inner slabs on the sections being considered, it was not considered feasible to evaluate the performance of the concrete pavement by a comparison of the measured faulting of the inner slabs.

A significant factor may be seen from a comparison of the faulting of the inner slabs with the faulting of the outer slabs. This shows the tremendous influence that traffic has on pumping and faulting of joints when other conditions are equal. The outer lane has carried the majority of traffic and has the most faulting. At present, the inner slabs of the water saturated section are carrying a large percentage of the traffic due to the exceptionally poor condition of the outer slabs. This is well illustrated in Figure 12 by the oil stains on the inner slabs. It is in this section that the most faulting of the inner slabs was found. This demonstrates how the poorer pavement performance follows the path of traffic.

Faulting in Outer Slabs

For this study the faulting at expansion joints in the outer slab is considered the best criterion for evaluating the effect of the subgrade treatments on the pavement performance. It is evident that the outer slabs have carried the bulk of the traffic which has produced faults of a measureable magnitude. Tables 14 and 15 show the faulting in the outer slabs of both lanes.

At the time of construction it was planned to make a direct comparison of the treated subgrade in the eastbound lane to the opposite untreated subgrade in the westbound lane. However, at the present time the untreated eastbound lane is in poorer condition than the opposite untreated westbound lane. From performance surveys made in 1946 on other primary highways leading to Chicago, the same is generally found to be true; that is, the south or eastbound lanes, as the case may be, are in worse condition than the north or westbound lanes. Measurements of the faulting in the outside slabs over approximately 4.3 miles in both lanes, where neither lane has received subgrade treatment, show 204 in. of faulting in the eastbound lane and only 95 in. in the westbound lane. A count of the number of patched joints for approximately 10 miles where neither lane has received subgrade treatment shows 179 patches in the eastbound lane and only 27 patches in the westbound lane. Based on these facts, it is believed that an unweighted comparison of the faulting in the test sections in the eastbound lane to the corresponding opposite untreated westbound lane would not present a true picture of the performance.

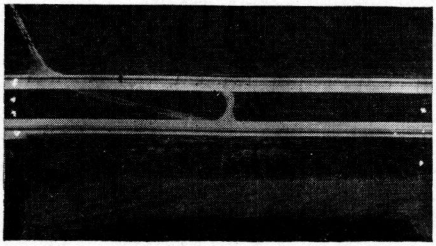

Figure 11. Aerial Strip Map of a Portion of the Test Section with a 3-in. Limestone Dust Subgrade treatment. The eastbound lane, which contains the subgrade treatment, is at the bottom of the photograph. The westbound lane is untreated.

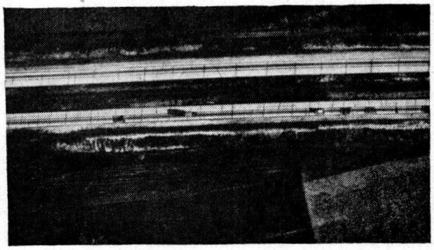

Figure 12. Aerial Strip Map of a Portion of the Test Section with a 12-in. Water Saturated Subgrade Treatment. The eastbound lane, which contains the treatment, is at the bottom of the photograph. The westbound lane is untreated.

Figs. 8 and 9 are representative views of portions of U.S. 30 constructed on silty clay where neither lane has received subgrade treatment. The views illustrate the generally poorer condition of the eastbound lane.

However, it is believed that a weighted across-the-road comparison of performance would be justifiable. In the 4.3 miles of highway of the same design and same soil type without subgrade treatment the eastbound lane showed 204 in. of faulting and the westbound lane only 95 in. It may be assumed that the same average ratio of faulting would hold true over the entire road. If this is true, and the test section had not been constructed, we could have expected to find 2.15 times as much faulting in the stretch of highway where the test sections are located as in the opposite lane. On this basis a weighted across-the-road comparison of the effect of the subgrade treatments on the amount of faulting was made. Table 19 shows both a weighted and unweighted across-the-road comparison. Considering the weighted comparison in Table 19, it can be seen that the subgrade treatments in order of their contribution to pavement performance are as shown in Table 20.

A value of 1.00 in Table 20 would indicate that the subgrade treatment did neither good nor bad. A value larger than 1.00 would indicate that the subgrade treatment was an improvement to the road.

Figures 10 to 16 inclusive are aerial views representative of each of the seven test sections. The views include both the treated and untreated lanes. The superiority of the pavement performance on the sand base course test sections is apparent when contrasted with the opposite untreated westbound lane. The pavement on the water condition of the pavement on the four other test sections, namely, those having subgrades treated with limestone dust, tar, emulsified asphalt and liquid asphalt, does not appear to differ from the condition of the opposite untreated lane. However, when you consider Figures 8 and 9, which show the generally

TABLE 19

COMPARISON OF THE FAULTING AT JOINTS IN OUTSIDE SLABS—TREATED AND UNTREATED SECTIONS—U S. 30

Station	Length	Eastbound Lanes		Westbound Lanes		Ratio of Amt. of Faulting per 1000 ft. of Untreated Sections to Treated Sections	Weighted Ratio of Amt. of Faulting per 1000 ft of Untreated Sections to Treated Sections Using a Factor = 2.15[a]
		Treatment of Subgrade	Faulting in. per 1000 ft.	Treatment	Faulting in. per 1000 ft.		
	ft.						
145+00 to 170+00	2,500	6-in. sand Base Course	2.4	None	5.9	2.46	5.29
170+00 to 195+00	2,500	3-in. compacted layer of natural soil mixed with limestone dust	4.6	None	4 3	0.93	1.99
195+00 to 221+00	2,600	12-in. Water Saturated Soil	15.7	None	2.4	0.15	0.32
250+00 to 275+00	2,500	3-in compacted layer of natural soil treated with tar (TC)	5.7	None	7.6	1.33	2.86
275+00 to 300+00	2,500	2-in. compacted layer of natural soil treated with Emulsified Asphalt (AES-1)	6.9	None	7.9	1.15	2.48
300+00 to 326+75 except 311+75 313+50	2,500	3-in. compacted layer of natural soil treated with a cut-back Asphalt (MC-1)	4.7	None	4.4	0.94	2.02
326+75 to 360+00	3,325	3-in. stabilized material base course	2.1	None	4.6	2.17	4.66

[a] See page 333 for discussion of this factor.

saturated subgrade test section appears in far poorer condition than the pavement on the opposite untreated lane. Although the pavement on the test section with the stabilized material base course is in much better condition than the pavement on the opposite untreated lane, it does not appear so in the aerial map because each lane has about the same number of cracks. When viewed directly the poorer condition of the eastbound when it is not treated, it is more apparent that these four treatments have improved the pavement performance.

Faulting in Cut and Fill Sections, Eastbound Lane

Although the preceding weighted across-the-road comparison of performance is considered justifiable, a comparison of the test sections to untreated portions in the eastbound lane would seem to present a truer picture of the pavement performance. For this purpose the eastbound lane was further subdivided into cut and fill sections and the faulting of the outer slabs tabulated as shown in Table 21.

By considering only the eastbound lane as many variables as possible are eliminated.

TABLE 20

Treatment	$\dfrac{2.15\times \text{ the Measured Faulting in the Untreated Westbound Lane}}{\text{Measured Faulting in the Treated Eastbound Lane}}$
6-in. Sand	5.29
3-in. Stabilized Material	4.66
3-in. Tar	2.86
2-in. Emulsified Asphalt	2.48
3-in. Liquid Asphalt (MC-1)	2.02[a]
3-in. Limestone Dust	1.99
12-in. Water Saturation	0.32

[a] Three large patched joints next to the intersection with State Route 55 were omitted as not being representative.

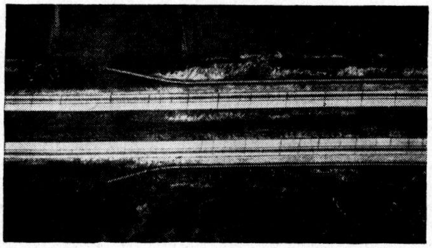

Figure 13. Aerial Strip Map of a Portion of the Test Section with a 3-in. Tar Subgrade Treatment. The eastbound lane, which contains the treatment, is at the bottom of the photograph. The westbound lane is untreated.

Whatever causes the generally poorer condition of the eastbound lane is essentially constant. The sandy subgrade soils are separated from the silty clay subgrade soils for this tabulation. Since the zone of weathering is shallow on the hills, subgrade soils of cut sections are essentially constant being mostly the silty-clay-parent-soil material of the area. The subgrade soils of the fill sections are somewhat variable, but are all silty clays. The depth of the fills could be a factor affecting the performance of the pavement, but no attempt was made to differentiate between shallow and deep fills.

From a summation of Table 21, the average faulting in the outer slabs of 8,900 ft of cut sections in the eastbound lane with untreated

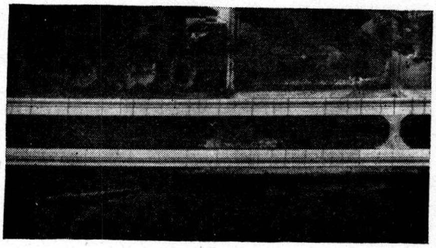

Figure 14. Aerial Strip Map of a Portion of the Test Section with a 2-in. Emulsified Asphalt Subgrade Treatment. The eastbound lane, which contains the treatment, is at the bottom of the photograph. The westbound lane is untreated.

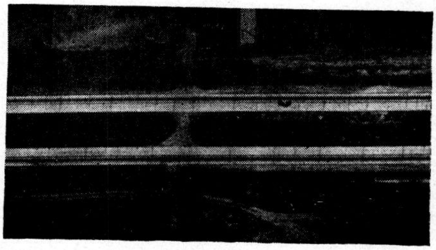

Figure 15. Aerial Strip Map of a Portion of the Test Section with a 3-in. Liquid Asphalt (MC-1) Subgrade Treatment. The eastbound lane, which contains the treatment, is at the bottom of the photograph. The westbound lane is untreated.

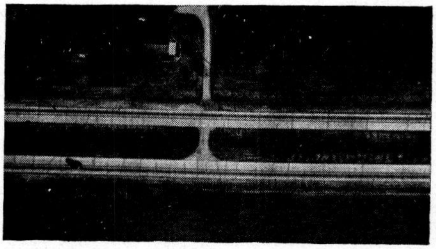

Figure 16. Aerial Strip Map of a Portion of the Test Section with a 3-in. Stabilized Material Base Course. The eastbound lane, which contains the base course, is at the bottom of the photograph. The westbound lane is untreated.

silty clay subgrade soils was 8.32 in. per 1000 ft. The average faulting for 11,100 ft of untreated silty clay fill sections in the eastbound lane was 11.04 in. per 1000 ft. A comparison of these values with the faulting in the test sections is given in Table 22.

From Table 22 it can be seen that for both cut and fill sections the subgrade treatment, with the exception of the water-saturation treatment, considerably reduced the amount of faulting. The water-saturation treatment shows itself to be a failure as is plainly visible in the field. At the time of the survey it contained 23 patched joints which is 35 percent of the total number of joints in the section.

Generally more faulting was found in fill than in cut areas. Exceptions to this are the sandy subgrade soils areas, the tar treated section, and the water-saturation treated section. No significant difference was found between the amount of faulting in the sections treated with 1.5 and 2.5 gal of MC-1 per sq yd.

It should be noted that the sand and stabilized material base course sections showed slightly better performance than the naturally sandy subgrade areas. It is believed that this is accounted for by the fact that a portion of the road considered to have a sand subsoil is built near the dividing line between sand and silty clay areas, and a few minor intrusions of silty clay may extend under the pavement. The pavement over the natural sandy soil area showed better performance than the pavements over treated soil sections and much

TABLE 21

FAULTING IN CUT AND FILL SECTION, U.S. HIGHWAY NO. 30, EASTBOUND LANE

Location	Length	Subgrade Treatment	Faulting in Outer Slabs in. per 1000 ft.	
			Cut	Fill
	ft.			
Sand Area West of Test Sections	1,680	None	3.3	
	1,150	None		2.6
Silty Clay Area West of Test Sections	4,250	None	7.7	
	4,000	None		8.0
	1,400	Sand Base Course	2.0	
	1,100	Sand Base Course		2.7
	950	Limestone Dust	4.2	
	1,550	Limestone Dust		5.0
	1,700	Water Saturation	18.1	
	900	Water Saturation		11.4
Silty Clay Area Between Test Sections	100	None	4.0	
	850	None		6.4
	2,000	Tar	5.8	
	500	Tar		5.0
	625	Emulsified Asphalt	6.1	
	1,875	Emulsified Asphalt		7.2
	1,450	Liquid Asphalt (MC-1)		
	900	1.5 gal per sq yd	4.6	
	550	2.5 gal per sq yd	4.3	
	1,050	Liquid Asphalt in (MC-1)		
	275	1.5 gal per sq yd		4.9
	775	2.5 gal per sq yd		5.0
	1,575	Stabilized Material Base Course	2.1	
	1,750	Stabilized Material Base Course		2.2
Silty Clay Area East of Test Sections	4,550	None	8.9	
	6,250	None		13.6

TABLE 22

Treatment	Faulting in. per 1000 ft	
	Cut Sections	Fill Sections
None (Silty Clay Subgrade)	8.3	11.0
6-in Sand	2.0	2.7
3-in Stabilized Material	2.1	2.2
None (Sandy Subgrade)	3.3	2.6
3-in Limestone Dust	4.2	5.0
3-in Liquid Asphalt—1.5 gal per sq yd.	4.6	4.9
2.5 gal per sq yd.	4.3	5.0
3-in Tar	5.8	5.0
2-in Emulsified Asphalt	6.1	7.2
12-in Water Saturation	18.1	11.4

saturation treatment, is in better condition than the pavement in the untreated portions of the same lane.

Riding Quality of the Test Sections

In determining the value of faulting to use for comparison purposes in this report, all measureable faulting was considered. A portion of this faulting would not be of such a magnitude at a joint as to be considered detrimental. To compare the various section on the basis of the number of large faults, or what might be called riding quality, a fault of over ¼ in. for any measurement at a joint was assumed to be detrimental faulting.

TABLE 23

EXPANSION JOINTS FAULTED OVER ¼ INCH AT ANY MEASUREMENT, U.S. HIGHWAY NO. 30

Location	Length	Subgrade Soil	Subgrade Treatment[a]	Faults over ¼ in. (No. per 1000 ft.)	
				East-bound Lane	West-bound Lane
	ft.				
West of Test Sections	3,380	Sand	None		1.8
	2,830	Sand		2.1	
	7,700	Silt & Clay			10.1
	8,250	Silt & Clay	None	9.6	
At and Opposite Test Sections	2,500	Silt & Clay	6-in. Sand	0.8	7.2
	2,500	Silt & Clay	3-in. Limestone Dust	6.8	4.0
	2,600	Silt & Clay	12-in. Water Saturation	18.0	1.5
Between Test Sections	950	Silt & Clay	None	13.7	3.2
At and Opposite Test Sections	2,500	Silt & Clay	3-in. Tar	8.8	10.4
	2,500	Silt & Clay	2-in. Emulsified Asphalt	8.4	17.2
	1,175[b]	Silt & Clay	3-in. Liquid Asphalt (MC-1)	7.6	5.1
	1,325[c]	Silt & Clay	3-in. Liquid Asphalt (MC-1)	7.5	6.0
	3,325	Silt & Clay	3-in Stabilized Material	0.3	9.9
East of Test Sections	10,200	Silt & Clay	None	15.3	2.8

[a] Subgrade treatment in eastbound lane only.
[b] 1.5 gal of MC-1 per sq. yd.
[c] 2.5 gal of MC-1 per sq. yd.

better performance than the untreated portions of the road. Material from this naturally sandy area was used for construction of the sand base course test section.

In comparing the test sections to each other and to untreated portions of the same lane, it is interesting to again study the aerial views of the road shown in Figures 8 to 16, inclusive. They show that the pavement in all of the test sections, with the exception of the water

For the various sections considered, the number of faults per 1000 feet have been tabulated in Table 23. The average number of faults over ¼ in. in magnitude for the untreated westbound lane is 6.8 per 1000 ft, while the average number in untreated portions of eastbound lane is 12.9 per 1000 ft, considering only areas with silty clay subgrade soil. This again indicated the generally poorer condition of the eastbound lane.

A comparison of the number of faults over ¼ inches for the sections in the eastbound lane are given in Table 24.

From Table 24 the lack of faults over ¼ in. in the sand and stabilized material treatment is apparent. The riding qualities of these two sections appears to be as good today after nine years of service as just after construction.

In the water-saturated-subgrade section, the faults over ¼ in. are 18 per 1000 ft or 72 percent of all joints. This is considerably more than on the untreated sections and gives an exceptionally poor riding surface.

No significant difference in the number of faults over ¼ in. in the limestone dust and bituminous treated sections can be seen. They average from 6.8 faults per 1000 ft to 8.8 per 1000 ft as compared to 12.9 faults per 1000 ft in the untreated portions of the lane.

TABLE 24

Treatment	Number of Faults over ¼ in. per 1000 ft.
None (Silty Clay Subgrade)	12 9
3-in Stabilized Material	0.3
6-in Sand...	0.8
None (Sandy Subgrade)	2.1
3-in Limestone Dust	6.8
3-in Liquid Asphalt—1 5 gal per sq yd	7.6
2 5 gal per sq yd	7 5
2-in Emulsified Asphalt	8 4
3-in Tar.. . . .	8.8
12-in Water Saturation	18.0

In the liquid asphalt treated sections there is no difference in the number of faults over ¼ in. between the portion treated with 1.5 gal of MC-1 per sq yd and that portion treated with 2.5 gal of MC-1 per sq yd.

CONCLUSIONS

In analyzing the effects of the subgrade treatments on the pavement performance of U.S. Highway No. 30, the major factors and influences have been considered and their effects analyzed. Many minor factors that would not materially effect the results in either direction have not been considered.

It is the opinion of the authors that, due to the generally poorer condition of the eastbound lane of U.S. Highway No. 30, all comparisons must be made on data secured in one lane only. Based on that fact, the following conclusions are drawn:

1. The results of the survey indicate that field installations provide an effective means for comparing or evaluating the merits of various subgrade treatments.
2. Further tests of installations constructed on a more uniform soil area would be highly advisable.
3. All subgrade treatments covered in this study with the exception of water-saturation, improved the performance of the concrete pavement.
4. The 6-in. sand and the 3-in. stabilized material base courses greatly improved the performance of the pavement by preventing pumping. Where these types of treatments were used the measurable faulting was reduced to about 25 per cent of the average measurable faulting found in untreated portions of the same lane. The number of faults over ¼ in. was reduced to about 5 percent of the number found in untreated portions of the same lane. Of the 64 joints in the sand base course section, only two were faulted over ¼ in. Of the 87 joints in the stabilized base course, only one was faulted over ¼ in. In the areas where longitudinal drains were installed in an attempt to minimize pumping, these were the only portions of the silty clay soil area where it was not necessary to place the drains.
5. The 3-in. limestone dust treatment improved the performance of the concrete pavement by reducing both the total measurable faulting and the number of faults over ¼ in. in magnitude to about 50 per cent of those found in untreated portions of the same lane.
6. The bituminous treatments (tar (TC), emulsified asphalt (AES-1), and liquid asphalt (MC-1) mixed with plastic subgrade soils) improved the performance of the concrete pavement. These treatments reduced both the total measurable faulting and the number of faults over ¼ inch in magnitude to about 65 per cent of those found in untreated portions of the same lane.

The thickness of bituminous treatment used in these sections may have been inadequate for the most effective improvement of the pavement performance.

No significant difference was found in pavement performance between the two sections treated with 2.5 and 1.5 gal per sq yd of liquid asphalt (MC-1).

Further studies using greater thicknesses of treatment and varying quantities of bituminous materials should be made before definite conclusions can be drawn as to the effectiveness of this method of subgrade treatment.

7. The amount of pumping and faulting in the area surveyed was found to occur almost entirely at expansion joints. No significant amount of pumping or faulting was found at cracks. No contraction joints were installed in this pavement.
8. Within the limits of this survey, more faulting was generally found in fill than in cut sections.
9. No significant difference was found between the performance of the two types of expansion joints used.
10. From observations since their installation in 1944, it appears that the longitudinal drains are in some measure effective in controlling pumping.
11. Aerial strip maps are an effective means of evaluating concrete pavement performance.

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DEPARTMENT OF TRAFFIC AND OPERATIONS

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THE USE OF THE AMERICAN TRANSIT MOTOR ABILITY TEST IN THE SELECTION OF BUS AND STREET CAR OPERATORS

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SYNOPSIS

The American Transit Motor Ability Test was applied to 290 bus and street car operators during their first week in training and the test scores were later correlated with the accident responsibility rates of the men per 100,000 hours of operation and with ratings of the individuals based on their total desirabilities as employees.

The test attempts to sample such functions as ability to learn quickly, ability to react quickly and accurately, ability to follow directions, ability to execute movements and coordinate them with visual stimuli, and avoidance of emotional disturbance in difficult situations. The test equipment utilizes a steering wheel, gear shift lever and two foot pedals which are activated by the subject in response to light patterns produced by a signal board carrying a series of small green, amber and red lights and a regulation traffic signal with green, amber and red lights. The test was administered in accordance with detailed instructions which allow the examiner little discretion. The tests are in five consecutive sequences which increase in difficulty and complexity.

The scoring of the test is in terms of accuracy and speed of reaction. The subject must make the correct movement for the stimulus presented and in terms of two time intervals; the initial response time and the lapsed time to perform the movement.

The product-moment correlation between accident responsibility rate and test scores was found to be: street car operators, r = 0.292; bus operators, r = 0.432; combined, r = 0.331.

The correlation of the test scores with supervisory ratings was 0.089, while the correlation of accident responsibility rate with supervisory ratings was 0.482.

Although the correlations between accident responsibility rate and test scores are too low for clinical diagnosis of individuals they are significant for establishing usable employment ranges of test scores. As used by the Capital Transit Company these are:

Scores of 65 or more indicate the most suitable candidates.

Scores between 50 and 64 indicate candidates who should be employed if other factors are favorable.

Scores of 49 or less indicate those who should be rejected.

Prior to the first World War industry appeared to give little thought to the problem of improving selection methods in their employment of personnel. The transit industry was no exception. Most industries were aware that individual differences existed in the output and efficiency of various employees; possibly a few were aware of the fact that much of the difference was due to abilities which had been inherited or acquired. How-